Hardware River TMDL
2nd Local Steering Committee Meeting
Revised - June 19, 2007

This document provides a summary of the performance and results of the computer model designed to predict bacteria concentrations in Hardware River. There were two impairments: one for the North Fork Hardware River and one lower in the watershed on the main reach of the Hardware River. All of the watershed below the confluence of North Fork with South Fork Hardware River will be referred to as the Lower Hardware River. Figure 1 shows the VADEQ and USGS station locations and the boundaries of North Fork and Lower Hardware River watersheds.

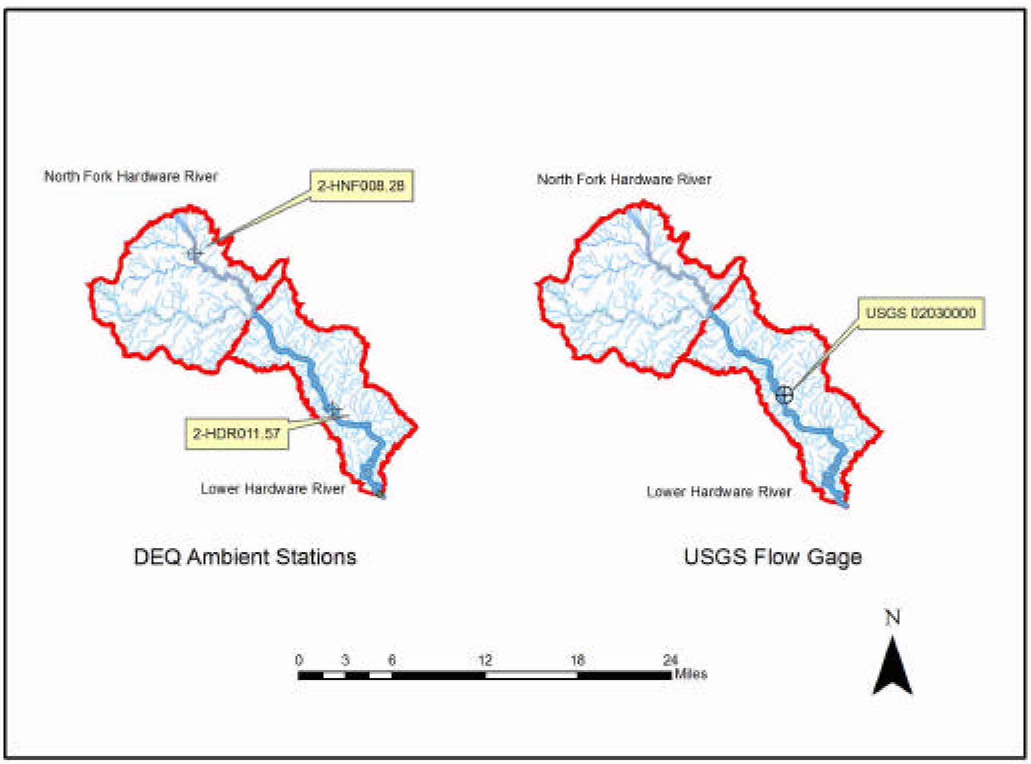

Figure 1. Watershed boundaries of North Fork and Lower Hardware River Watersheds.

Model Calibration

Calibration is the process of adjusting model parameters until the computer model produces the best possible fit with observed data. In essence, it is a “test” to see if the model can accurately predict the Hardware River watershed hydrologic conditions. Next, the water quality portion of the model is tested by comparing the predicted bacteria concentrations with observed bacteria concentrations in North Fork and Lower Hardware River watersheds.

Hydrologic Calibration and Validation

The hydrologic calibration period was September 1, 1989 to December 31, 1995. The hydrologic validation period was from June 1, 1997 to August 31, 2001. The output from the Hydrologic Simulation Program Fortran (HSPF) model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range. The time-step used in the hydrologic simulations was 1 hour. Observed daily flow data for Hardware River were available from the USGS monitoring station 02030000 (see Figure 1), below Briery Run. Daily flow data were used in the hydrologic calibration/validation. Meteorological data were obtained primarily from National Weather Service COOP station at Bremo Bluff (COOP ID 440993) in Fluvanna County. Bremo Bluff is located roughly 10 miles east of the watershed. A combination of manual calibration using HSPEXP and automatic calibration using the Parameter Estimation (PEST) software were used to do the calibration and validation for the Hardware River watershed as described by Kim et al. (2007a).

There was good agreement between observed and simulated flow for the calibration period based on the visual comparisons and the HSPEXP statistics. The observed and simulated flows for the calibration period are shown in Figure 2.

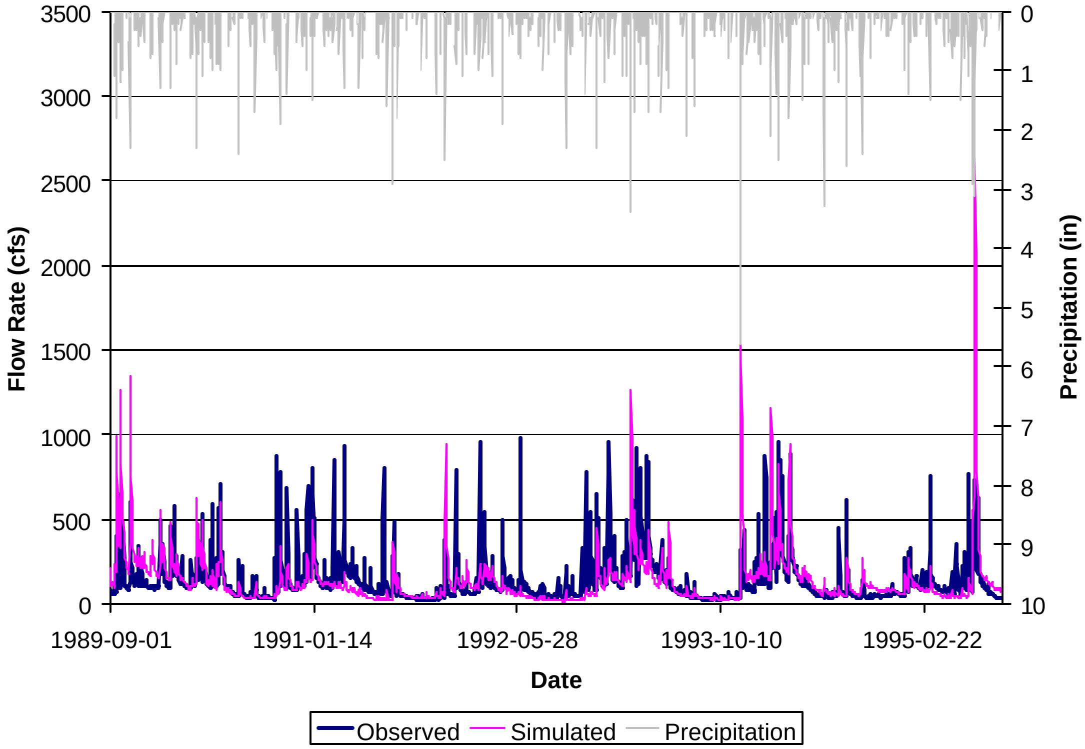

Figure 2. Observed and simulated flows and precipitation for Hardware River for the calibration period (September 1, 1989 to December 31, 1995).

The quality of the calibration is demonstrated further in the statistics considered by HSPEXP. The HSPEXP statistics are given in Table 1, along with their default criteria and the values from the Hardware River calibration. The calibration is satisfactory based on the visual comparisons of the simulated and observed flow and the HSPEXP statistics shown in Table 1.

Table 1. Summary statistics for the calibration period.

	Simulated	Observed	Error (%)	Default Criterion	Criteria met
Total Runoff (in)	99.670	95.553	+4.3	10%	Y
Average Annual Total Runoff (in)	16.612	15.926	+4.3	10%	Y
Total of Highest 10% of Flows (in)	37.440	32.676	+14.6	15%	Y
Total of Lowest 50% of Flows (in)	18.220	20.030	-9.0	10%	Y
Total Winter Runoff (in)	31.160	29.035	+7.3	na	na
Total Summer Runoff (in)	18.360	16.676	+10.1	na	na

na = not applicable; these are not criteria directly considered by HSPEXP

The hydrologic validation period used was September 1, 1997 through August 31, 2001. The observed and simulated flows for the validation period are shown in Figure 3. Both the peak flows and low flows were captured by the model (see Figure 3). The quality of the validation is demonstrated further in the HSPEXP (see Table 2). The visual comparisons of the simulated and observed flow support a satisfactory validation.

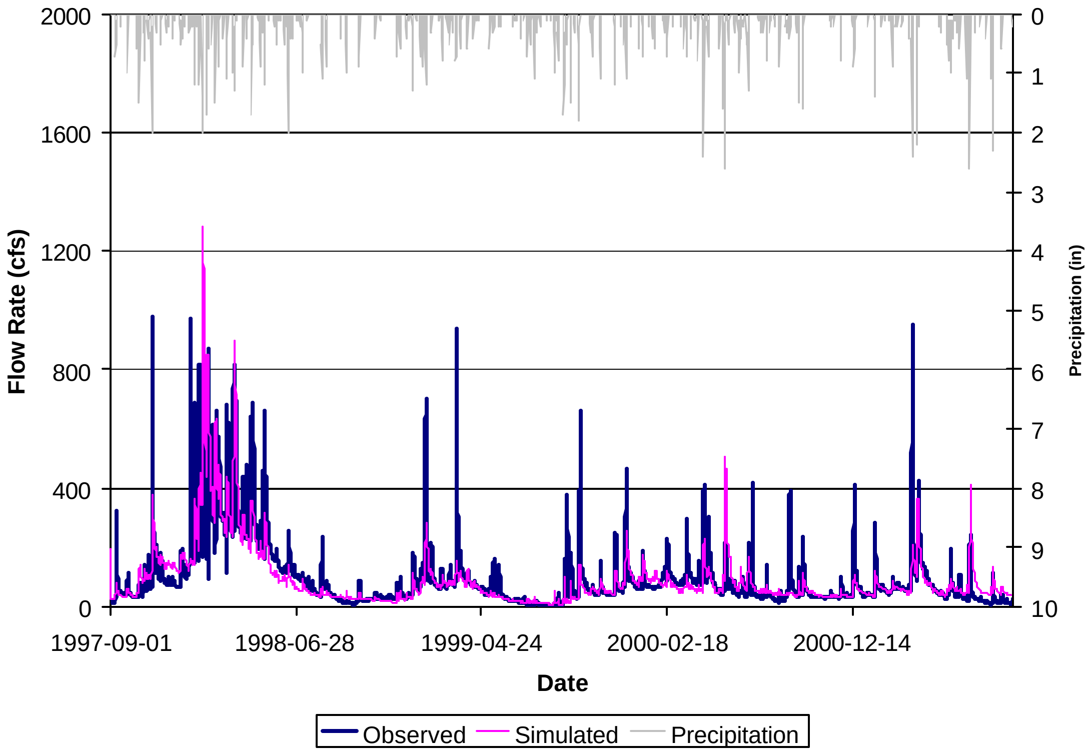

Figure 3. Observed and simulated flows and precipitation for Hardware River for the validation period (September 1, 1997 through August 31, 2001).

Table 2. Summary statistics for the validation period.

	Simulated	Observed	Error (%)	Criterion	Criteria met
Total Runoff (in)	43.780	45.668	-4.1	10%	Y
Average Annual Total Runoff (in)	10.945	11.417	-4.1	10%	Y
Total of Highest 10% of Flows (in)	16.820	18.270	-7.9	15%	Y
Total of Lowest 50% of Flows (in)	8.800	8.000	+10.0	10%	Y
Total Winter Runoff (in)	15.840	14.801	+7.02	na	na
Total Summer Runoff (in)	6.320	5.404	+16.95	na	na

na = not applicable; these were not criteria directly considered by HSPEXP

Water Quality Calibration

The water quality calibration was performed at an hourly time step using the HSPF model. There were four water quality monitoring stations, 2-HNF000.10, 2-HNF005.03, HNF008.28, and HNS002.40, available for North Fork. Only the 2-HNF008.28 station, which is located in the upper portion of North Fork Hardware (see Figure 1), was used for the calibration. This station has 19 observations of fecal coliform data across 11 years. The other stations have less than 2 years of *E. coli* data. The period of January 1, 1995 to December 31, 2005 was selected for calibration because it includes all of the data from station 2-HNF008.28. North Fork was calibrated first and then output from the calibrated North Fork model run was treated as an inflow for the Lower Hardware River calibration.

Two water quality monitoring stations were considered for the calibration of the Lower Hardware River water quality model. Over 80 observations are available from Station 2-HRD011.57 (see Figure 1). The other station has less than 2 years of *E. coli* data. The large amount of data available at station 2-HRD011.57 allowed for both calibration and validation of the model for the Lower Hardware River watershed. The calibration period was January 1, 1995 to December 31, 1998 and the validation period was January 1, 2000 to December 31, 2005. Output from the HSPF model was generated as an hourly timeseries and daily average timeseries of fecal coliform concentrations at the two subwatershed outlets corresponding to the two monitoring station locations.

Since the observed data are collected via grab samples on a monthly basis (at best), it is not practical to expect a daily-average simulated value on a specific day to exactly match such data. Therefore, the standard methods used for calibration of water quality models were augmented. The procedures outlined in Kim et al. (2007b), which include a minimum-maximum 5-day window statistic, instantaneous violation rates, geometric mean, arithmetic mean, and other statistics, were used to augment the standard criteria used in the water quality calibration of HSPF. Finally, visual comparisons of the simulated daily average to the observed data were considered to provide the best overall picture of the quality of the calibration run.

North Fork Water Quality Calibration

Several key input parameters were altered during the calibration process. These parameters included: the washoff factor (WSQOP); fecal coliform production rates for livestock and wildlife; and the volume used to represent flow stagnation in the reaches. The final goodness-of-fit measures for the calibration are listed in Table 3. Figure 4 shows the daily max, min, and average of simulated values for the final calibration run. Based on the goodness-of-fit parameter values and the visual comparisons, the water quality calibration for North Fork Hardware River was considered acceptable.

Table 3. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for station 2-HNF008.28.

	Geometric Mean*	Average*	Median*	MIN*	MAX*	IVR** (%)	% in 5-day Range
Observed	307	791	200	100†	4,600	37	
Simulated	231	760	607	10	1,247,889	40	80

* units cfu/ 100 ml
**IVR = instantaneous violation rate
†Capped value

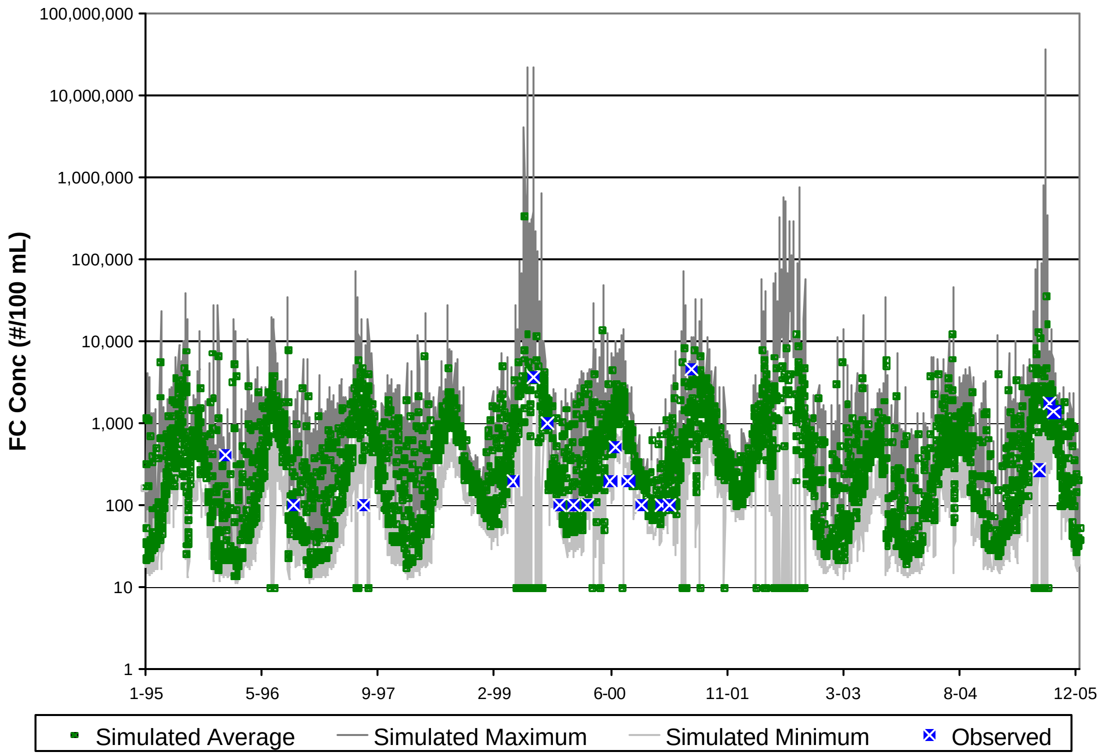

Figure 4. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 2-HNF008.28 for the calibration (January 1, 1995 to December 31, 2005).

Lower Hardware River Water Quality Calibration/Validation

As with the North Fork calibration, several key input parameters were altered during the calibration and validation of the Lower Hardware River. These parameters included: the washoff factor (WSQOP); fecal coliform production rates; and the volume used to represent flow stagnation in the reaches. The goodness-of-fit parameter values are presented in Table 4. Figure 5 shows the daily min, max, and average of the simulated values for the final calibration run. Both the simulated geometric mean and instantaneous violation rate compared well with the observed statistics. Based on the goodness-of-fit parameter values and the visual comparisons the water quality calibration for Lower Hardware River was considered acceptable.

Table 4. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the calibration period for Lower Hardware River.

	Geometric Mean*	Average*	Median*	MIN*	MAX*	IVR** (%)	% in 5-day Range
Observed	156	398	100	25	5,000	22	
Simulated	221	423	226	10	24,485	36	59

*units cfu/ 100 ml
**IVR = instantaneous violation rate

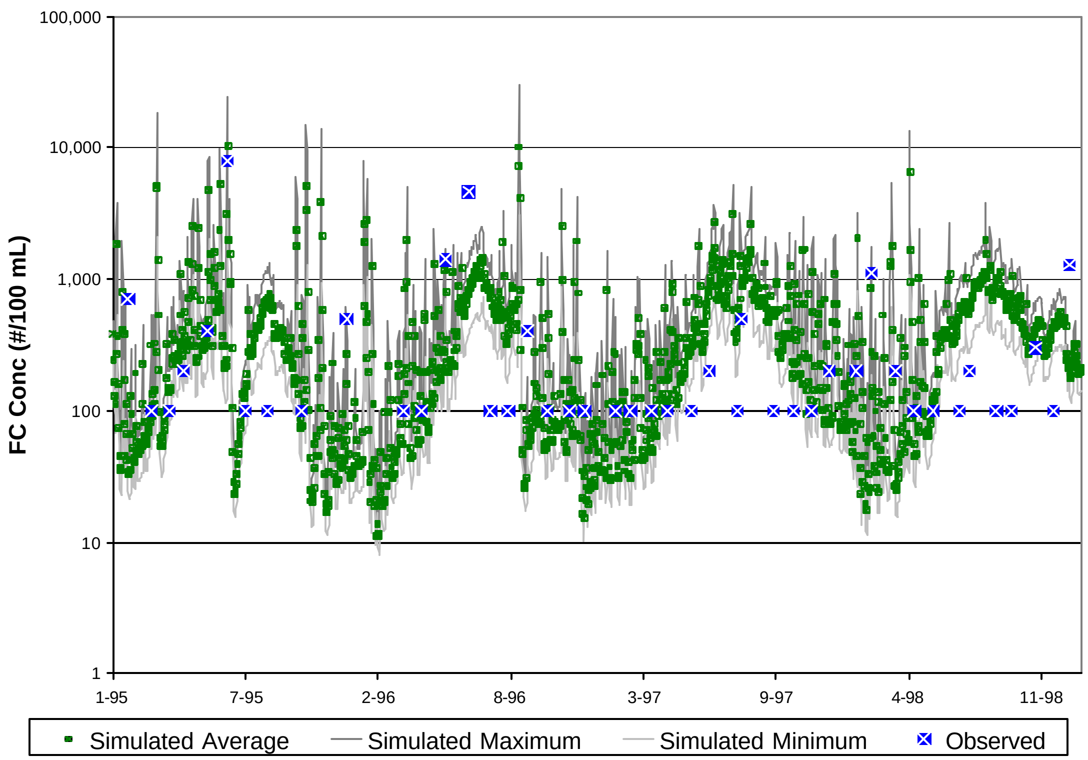

Figure 5. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 2-HRD011.57 for the calibration (January 1, 1995 to December 31, 1998).

After the calibration, the model was run for a different period (January 1, 2000-December 31, 2005) as a validation to ensure the calibrated input parameters were appropriate. The goodness-of-fit statistics for the validation run are listed in Table 5. Figure 6 shows the daily min, max, and average of the simulated values for the validation. The simulated concentrations varied with the seasonal trend. Based on the goodness-of-fit parameter values and the visual comparisons both the water quality calibration and validation for Lower Hardware River were considered acceptable.

Table 5. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the validation period for Lower Hardware River.

	Geometric Mean*	Average*	Median*	MIN*	MAX*	IVR** (%)	% in 5-day Range
Observed	193	525	100	100†	8,000†	23	
Simulated	357	627	452	26	24,964	45	33

*units cfu/ 100 ml
**IVR = instantaneous violation rate
†Capped value

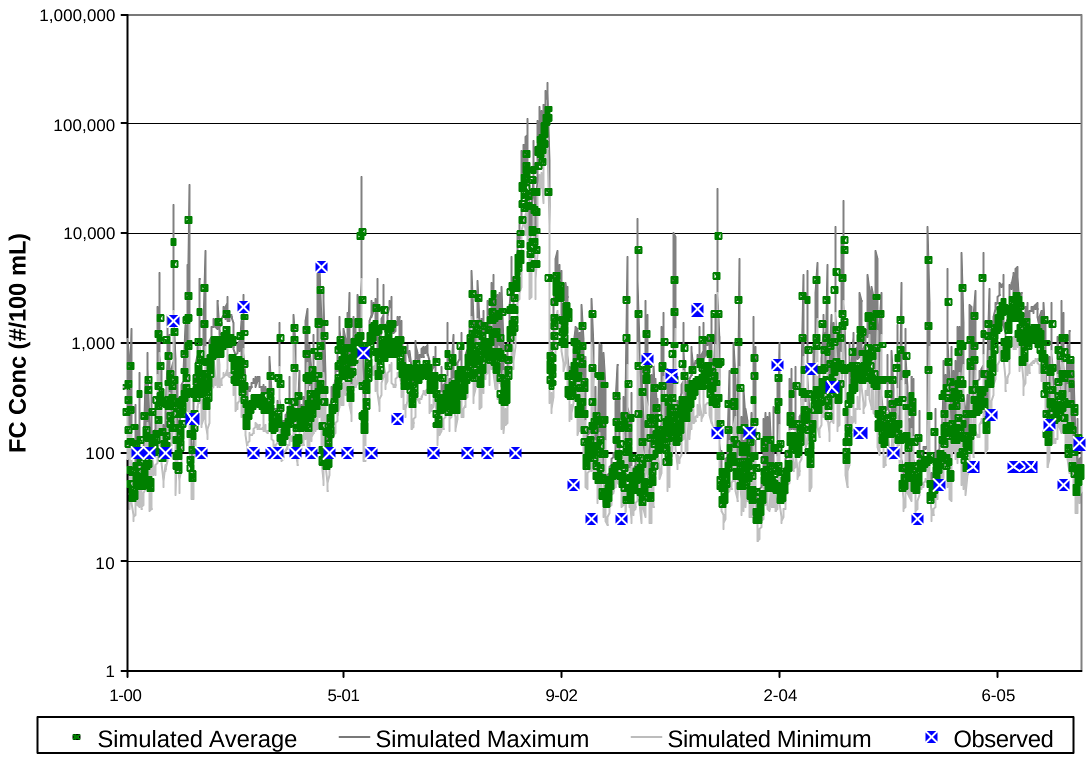

Figure 6. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values at station 2-HRD011.57 for the validation period (January 1, 2000 to December 31, 2005).

LSC Question – Would you agree that the model appears to be predicting in stream flow and bacteria concentrations relatively well?

Model Results – Existing Conditions

Following the hydrologic and water quality calibrations of North Fork and Lower Hardware River watersheds, the model was used to simulate existing conditions (1996 to 1998). Tables 6 and 7 summarize the relative contributions of bacteria from the various sources to in-stream concentrations for the North Fork and Lower Hardware Rivers. These tables highlight several interesting results:

Table 6. Relative Contributions of Various Bacteria Sources Under Existing Conditions for North Fork Hardware River.

Source	**Mean Daily *E. coli* Concentration by Source, cfu/100 mL**	**Relative Contribution by Source**
All Sources	249	
Nonpoint source loadings from pervious land segments	180	72%
Direct nonpoint source loadings to the stream from wildlife	14	6%
Direct nonpoint source loadings to the stream from livestock	55	22%
Interflow and groundwater contribution	< 0.1	< 0.1%
Straight-pipe discharges to stream	< 0.1	< 0.1%
Nonpoint source loadings from impervious land use	< 0.1	< 0.1%
Point sources*	< 0.1	< 0.1%

*Contributions from point sources assumed to be discharging at their permitted limits.

Table 7. Contributions of Various Bacteria Sources Under Existing Conditions for Lower Hardware River.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100 mL	Relative Contribution by Source
All Sources	250	
Nonpoint source loadings from pervious land segments	32	13%
Direct nonpoint source loadings to the stream from wildlife	44	18%
Direct nonpoint source loadings to the stream from livestock	141	57%
Interflow and groundwater contribution	16	6%
Straight-pipe discharges to stream	16	6%
Nonpoint source loadings from impervious land use	< 0.1	< 0.1%
Point sources*	< 0.1	< 0.1%
North Fork source only	0.7	-

*Contributions from point sources assumed to be discharging at their permitted limits.

LSC Question – Are the model results for existing conditions consistent with your knowledge of the area?

Model Results – Reduction Scenarios

Once the model is providing accurate results, it is used to investigate different reduction scenarios that could be used to meet the water quality standards. Two basic milestones are considered. The first is the level of reduction necessary to meet the water quality standard 89.5% of the time (less than 10.5% instantaneous violation rate). The second is the level of reductions necessary to meet the water quality standards all of the time. This becomes the TMDL, the total maximum daily load of bacteria that the North Fork and Lower Hardware Rivers can receive and still meet the water quality standard all of the time.

The suggested reduction scenarios and the resulting violations rates summarized in Tables 8 and 9 are based on input from the Local Steering Committee.

LSC Question – Are the TMDL and Phase I scenarios acceptable for North Fork and Lower Hardware Rivers?

Table 8. Bacteria Allocation Scenarios for North Fork Hardware River.

Scenario	Fecal Coliform Loading Reduction (%)							% Violation of *E. coli* Standard	
	Cattle DD	Cropland	Pasture	Wildlife DD	Straight Pipes	Residential PLS	Forest	Geometric Mean	Instantaneous
Baseline	0	0	0	0	0	0	0	44%	26%
01	100	0	0	0	100	0	0	8%	21%
02	100	98	98	0	100	98	0	0%	1%
03	100	99	99	0	100	99	0	0%	0%
04	70	70	70	0	100	70	0	17%	10%

TMDL Allocation

Phase I Implementation Options

Table 9. Bacteria Allocation Scenarios for Lower Hardware River.

Scenario	North Fork Run Used	Fecal Coliform Loading Reduction (%)							% Violation of *E. coli* Standard	
		Cattle DD	Cropland	Pasture	Wildlife DD	Straight Pipes	Residential PLS	Forest	Geometric Mean	Instantaneous
Baseline		0	0	0	0	0	0	0	50%	40%
01	**03**	100	100	100	0	100	100	0	11%	1%
02	**03**	100	100	100	10	100	100	0	1%	1%
03	**03**	100	100	100	25	100	100	0	0%	0%
04	**04**	75	75	75	0	100	75	0	17%	10%

TMDL Allocation

Phase I Implementation Options

References

Kim, S. M., Kim, S. M., B. L. Benham, K. M. Brannan, R. W. Zeckoski. 2007a. Comparison of Hydrologic Calibration of HSPF Usin Automatic and Manual Methods. Water Resources Research, 43 W01402

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